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CRITICAL DEPTH TESTS OF BULK TNT FLAKE EXPLOSIVE

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A series of propagation tests were conducted with a commercially available (serpentix), corrugated, rubber belt conveyor containing bulk TNT flake explosive. Tests were performed to determine whether this conveyor could safely transport the explosive at a critical depth of 38 mm (1.5 in.). Test results indicated that the 0.61-metre (2'-0") wide serpentix conveyor, with a 25 mm (1.0-in.) minimal separation of explosive between troughs, could prevent detonation propagation.

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20. Abstract (continued)

These tests were performed specifically for operations at the Lone Star Army Ammunition Plant; however, the results are applicable to other similar loading lines.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

SUMMARY

The series of tests described in this report cover only one phase of an overall safety engineering program entitled 'Safety Engineering in Support of Ammunition Plants" conducted under the guidance of the Manufacturing Technology Division, Large Caliber Weapons Systems Laboratory, ARRADCOM, Dover, New Jersey, for the U.S. Army Armament Command (ARMCOM).

This series of tests were performed to determine whether a commercially available, corrugated rubber belt conveyor of the Serpentix variety could safely transport a uniform depth of 38-mm (1.5-in) of bulk TNT flake explosive. In a previous study (Technical Report No. 5014, November 1976), it was determined that Composition B flake could safely be transported in this manner. This system would be used to carry the explosive between automated inspection buildings and melt/pour facilities at the Lone Star AAP.

The Serpentix conveyor was chosen to utilize the air gap concept between quantities of bulk TNT flake explosive. All tests were conducted using this corrugated rubber belt conveyor backed by a 25-mm (1-in) by 0.3-m (1-ft) pine board supported by two cinder blocks at each end. The conveyor was housed in a 2.44-metre (8-ft) long simulated aluminum tunnel, 0.61-metre (2-ft) wide by 0.92 metre (3 ft) high. The corrugations of the conveyor provided a 51-mm (2-in) gap between the explosives in adjacent troughs.

Since it was previously determined that the Serpentix conveyor could safely transport Composition B flake at a critical depth of 38 mm (1.5 in), the tests with bulk TNT flake were conducted using the one-donor, two-acceptor setups. Twenty-five high-order donor detonations were conducted and no propagation of a high-donor detonation to the acceptor trough on either side of the donor was observed.

This sample size of 50 observations was sufficient to show that the Serpentix rubber belt conveyor, housed in a simulated tunnel, could safely transport a uniform depth of 38 mm (1.5 in) of bulk TNT flake explosive at a 93 percent reliability for a 95 percent confidence level.

INTRODUCTION

Background

At the present time, an Army-wide expansion program is underway to upgrade the existing, and to develop new explosive manufacturing and LAP (Load, Assemble and Pack) facilities. Substantial increases in the production cost-effectiveness and improvement in facility safety are the major goals of this program. As a part of this overall program, the Manufacturing Technology Division, Large Caliber Weapon Systems Laboratory, ARRADCOM, Dover, New Jersey, under the direction of the U.S. Army Armament Command is engaged in the development of safety criteria. The ARRADCOM program entitled "Safety Engineering in Support of Ammunition Plants" will use the criteria developed from tests for the design of all future explosive production installations.

The test program described in this report was undertaken to assess a means of safely transporting bulk TNT explosive via conveyors for use between automated inspection buildings and melt/pour facilities located at the Lone Star Army Ammunition Plant in Texarkana, Texas. The Army Safety Manual (Army Materiel Command Regulation AMCR 385-100, Table 17-1) lists the safe spacing of munitions and explosives in a boxed or pre-packaged condition; however, there is no criteria for conveying loose bulk TNT flake explosive. The information in this report is applicable to other similar LAP facilities.

Objective of Test Program

The objective of this test program was to determine whether a corrugated rubber belt Serpentix conveyor could safely transport bulk flake TNT explosive. This was accomplished by a series of tests that would determine the probability of propagation of a high-order detonation as a result of an accidental explosion of bulk TNT flake transported on the Serpentix conveyor.

Criteria for Confirmatory Tests

In the report "Critical Depth Tests of Composition B Flake" it was determined that a 38-mm (1.5-in) depth of explosive in a Serpentix conveyor would prevent propagation of a high-order detonation along the conveyor. As a result, in the 25 tests using bulk TNT flake explosive, each donor was considered to have two acceptor specimens. No high-order propagation of the donor detonation occurred in any test. These 50 observations provide

at least a 93 percent reliability for a 95 percent confidence level as explained in the section "Analysis of Test Results."

TEST CONFIGURATIONS

General

The test program was initiated to determine the critical depth of bulk TNT explosive on conveyors that connect the automatic inspection building with the melt/pour facilities of the 105-mm LAP line at Lone Star AAP. The critical depth is defined as the depth of explosive bed on the conveyor which will not aid in spreading an accidental detonation from one end of the conveyor to the other, and at the same time be compatible with the production rate of the plant. This production rate should allow the flow of bulk TNT explosive in a continuous fashion and in sufficient quantity so as to not interrupt the process.

Based upon a previously conducted study of critical depths of Composition B Flake on conveyor systems (Technical Report No. 5014, dated November 1976), it was determined that the only commercially available conveyor system that was suitable for bulk explosive conveyance was the Serpentix or corrugated conveyor belt. Due to a time factor and a desire to reduce testing costs, the Serpentix conveyor was the only one tested during this program.

Test Arrangement

A series of 25 tests were conducted using the one-donor, two-acceptor technique, with the high-order initiation of the centrally located donor. Each test setup consisted of 11 trough sections of the Serpentix rubber belt conveyor (Figures 1 and 2) backed with a 25-mm (1.0 in) thick wooden plank and supported 0.38 metre (15 inches) off the ground by cinder blocks. The whole Serpentix conveyor was housed in an aluminum tunnel 0.61 metre (2.0 feet) wide by 0.92 metre (3.0 feet) high and 2.44 metres (8.0 feet) in length (Figures 3, 4 and 5) which simulated the actual weather-protected tunnels between the loading buildings of the ammunition plant.

All 11 troughs of the Serpentix conveyor contained bulk TNT explosive, with acceptor troughs numbered 1 through 5 located on the left (Figure 1). Trough No. 6 was the donor and acceptor troughs numbered 7 through 11 were on its right. Each of the 11 troughs was filled with approximately 1.25 kilograms (2.75 pounds) of bulk TNT explosive which constituted a uniform depth of 38 mm (1.5 inches) across the top of the rib separating each trough.

Unlike past test programs of similar magnitude, Composition C4 was not utilized to initiate the donor, as sufficient quantities were unavailable at the test site. Instead, a 0.46-metre (18.0-inch) length of primer cord was looped with both ends joined and taped to an M-7 blasting cap. This ignition assembly was then placed in the donor trough (Figure 6) and covered with the bulk TNT explosive. In all cases, this method of initiation produced a high-order donor detonation.

ANALYSIS OF TEST RESULTS

In the series of 25 confirmatory tests, there was no high-order propagation of the donor detonation. Since each donor had acceptor specimens on either side, a total of 50 observations were made.

The results of the individual test detonations are presented in Table 1. With the exception of Tests Nos. 18 and 19, there was no propagation of the donor detonation. In confirmatory Test No. 18, low-order propagation of the donor detonation occurred in the nearest left acceptor and, in Test No. 19, a low-order propagation of the donor detonation occurred to both the nearest left and right acceptors. Figures 7 and 8 show the post-test results. Note that in both cases the section of Serpentix conveyor that contained the donor was destroyed by its high-order detonation, while very little damage was inflicted on the rest of the conveyor.

Variations in manufacturing tolerances, materials, wear, etc., require that statistical reasoning be employed in the comparative interpretation of the test data. Such systematized reasoning allows that the actual probability of the propagation of an explosive incident is a direct function of the number of propagation occurrences in the test series conducted.

In statistical terms, the probability of propagation at any given level of confidence is a function of the measured probability and the sample size. The level of confidence referred to is a reflection of the fact that all possible acceptors cannot be tested. As the theoretical sample size of acceptors decreases from infinity, there is a decreasing confidence that the sample represents the total polulation; i.e., all acceptors. In practice, a sample size is selected to yield an acceptable confidence level. For a given measured probability of an event, there are fixed maximum and minimum probabilities associated with the specific confidence level. These values are referred to as confidence limits. These confidence limits depend on the specific probability distribution governing the event.

It may be stated that only two conditions of the acceptors after a test are possible. These are detonated or undetonated and correspond to the occurrence of propagation or non-propagation, respectively. Since the presence or absence of propagation for one acceptor is independent of that for another, the binomial probability distribution applies. Figure 9 shows the relationship

between sample size, confidence level and the maximum probability of detonation when there is no detonation.

Since the probability of detonation for each acceptor may be considered independent of the other, the sample size for this series is 50. Referring to Figure 9, the upper limit on the probability of propagation is 93 percent at the 95 percent confidence level. This is equivalent to stating that in a large number of tests, 95 out of 100 times, the probability of propagation of an explosive event will be less than or equal to 93 percent. Similarly, a 99 percent confidence level corresponds to an upper probability limit of 90 percent. These values indicate the quality of the tests and the reliance that can be placed on the conclusions drawn from the testing.

CONCLUSION

A 38-mm (1.5-in) depth of bulk TNT explosive on a 0.61-metre (24-inch) wide commercially available Serpentix (corrugated) rubber belt conveyor, as used in this test program, with a definite separation of 25 mm (1.0 in) between conveyor troughs, will prevent propagation of a high-order explosion along the entire conveyor system.

TABLE 1

Summary of test results

Test No.	Acceptor	Results*
1	Left	NDP
	Right	NDP
2	Left	NDP
	Right	NDP
3	Left	NDP
	Right	NDP
4	Left	NDP
	Right	NDP
5	Left	NDP
	Right	NDP
6	Left	NDP
	Right	NDP
7	Left	NDP
	Right	NDP
8	Left	NDP
	Right	NDP
9	Left	NDP
	Right	NDP
10	Left	NDP
	Right	NDP
11	Left	NDP
	Right	NDP
12	Left	NDP
	Right	NDP
13	Left	NDP
	Right	NDP
14	Left	NDP
	Right	NDP

* NPD - No Detonation Propagation

TABLE 1
(continued)

Test No.	Acceptor	Results*
15	Left	NDP
	Right	NDP
16	Left	NDP
	Right	NDP
17	Left	NDP
	Right	NDP
18	Left	LOD nearest trough only (#5)
	Right	NDP
19	Left	LOD nearest trough only (#5)
	Right	LOD nearest trough only (#7)
20	Left	NDP
	Right	NDP
21	Left	NDP
	Right	NDP
22	Left	NDP
	Right	NDP
23	Left	NDP
	Right	NDP
24	Left	NDP
	Right	NDP
25	Left	NDP
	Right	NDP

* NDP - No Detonation Propagation
LOD - Low Order Detonation

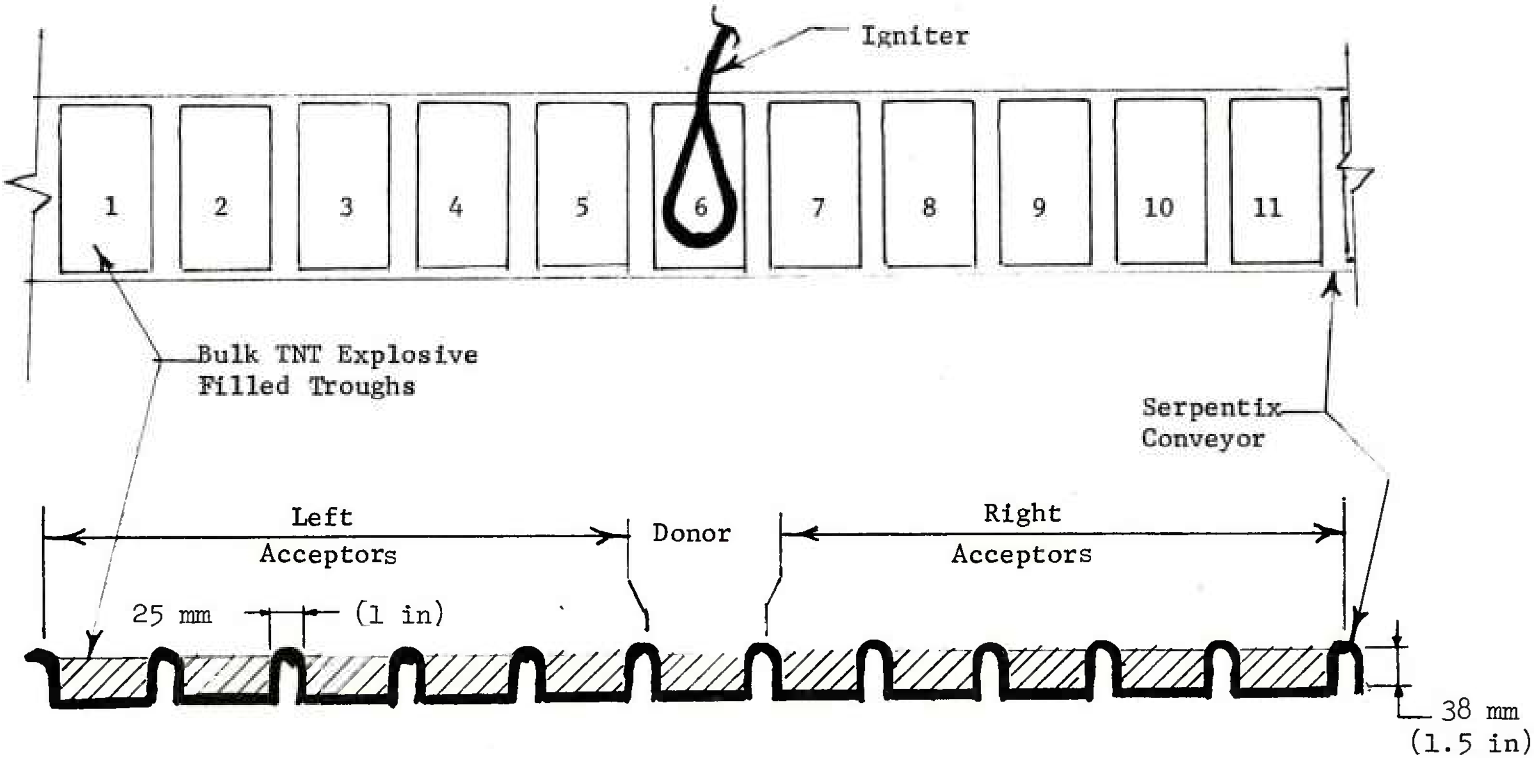

Fig 1 - Serpentix conveyor layout

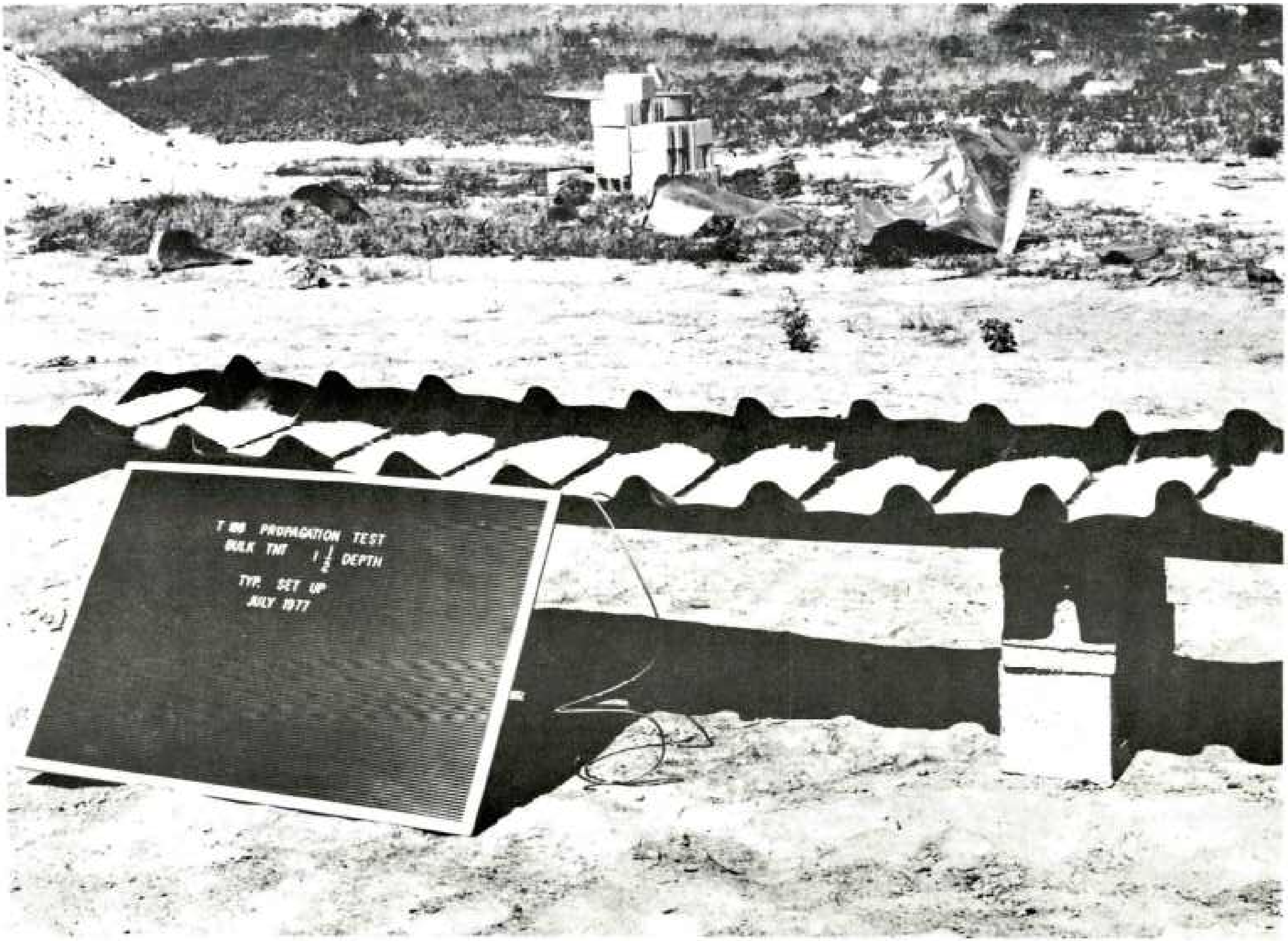

Fig 2 - Serpentix conveyor test setup

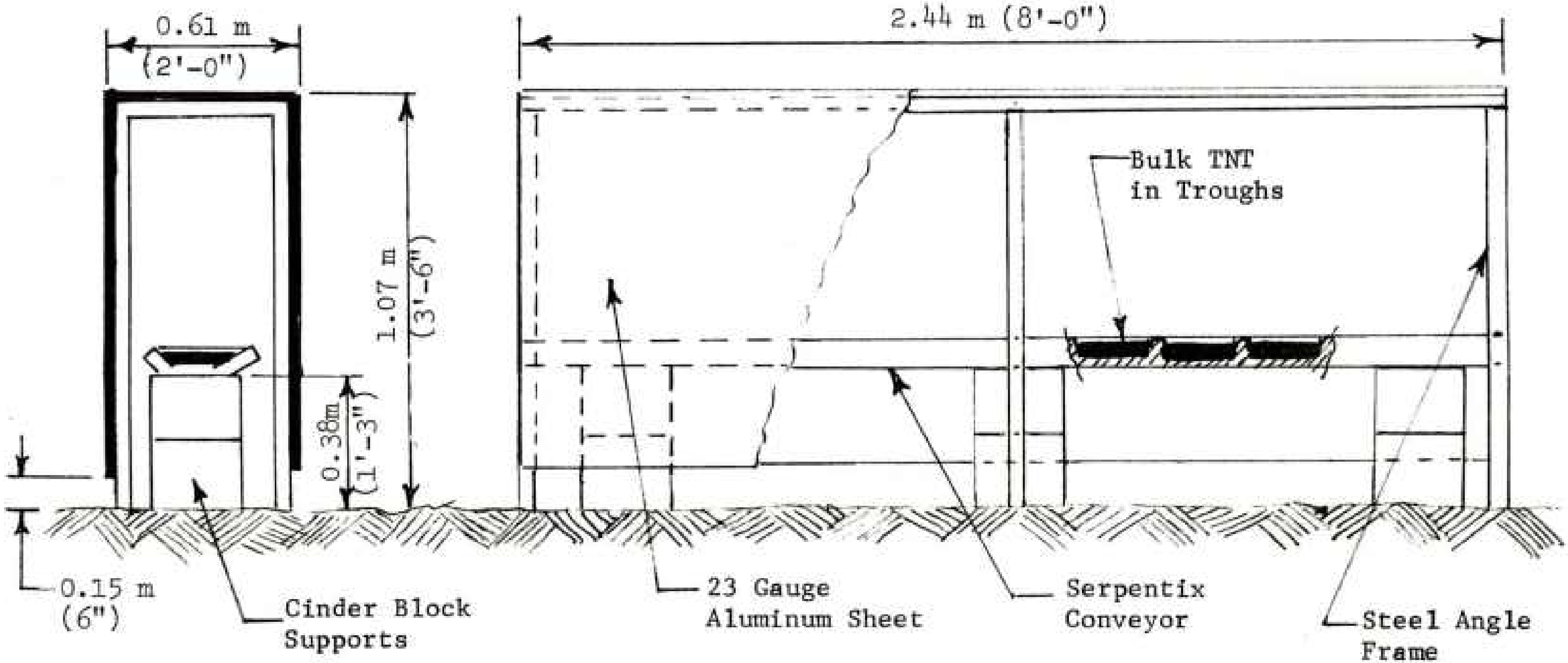

Fig 3 - Simulated tunnel layout

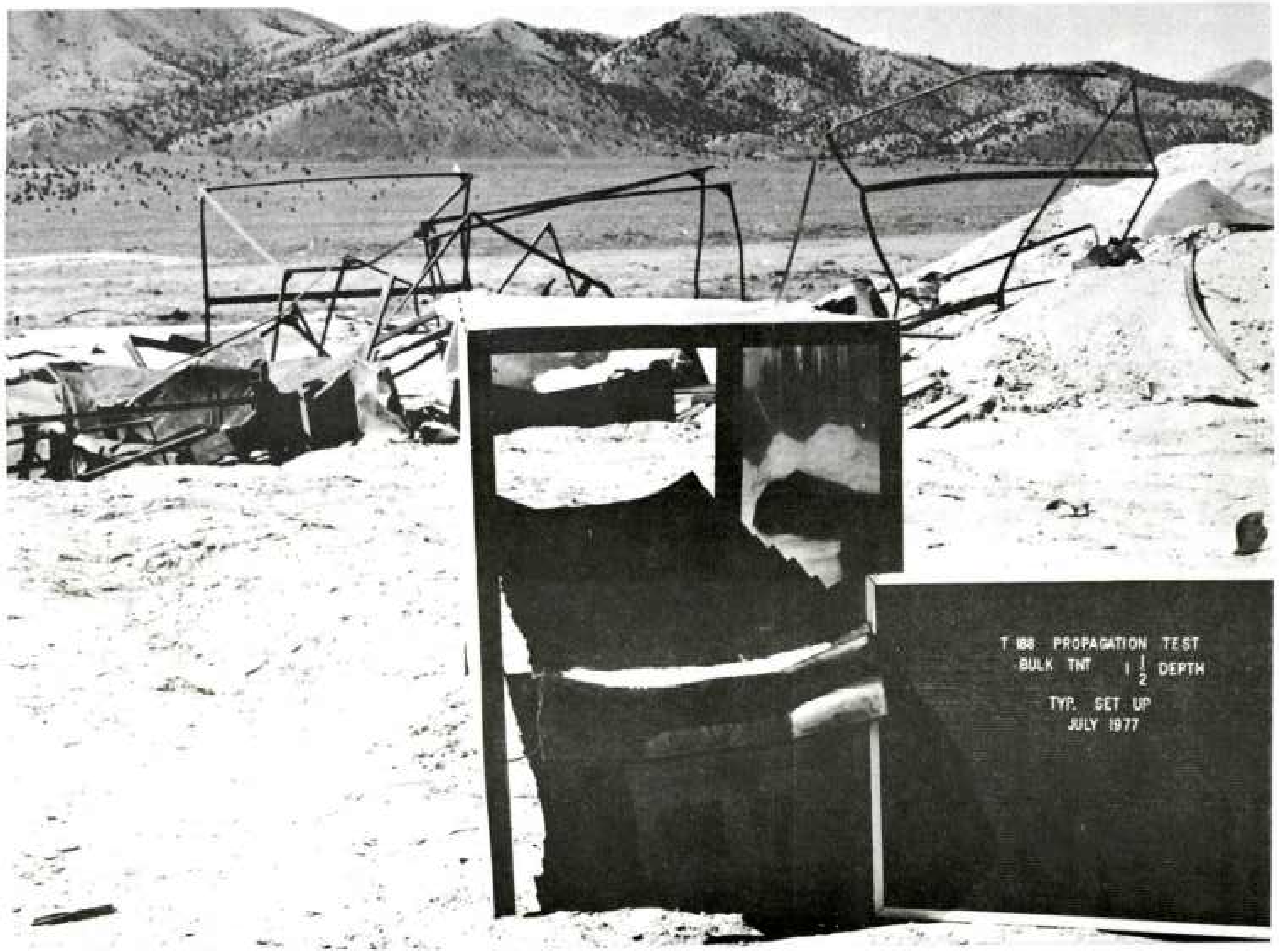

Fig 4 - Simulated tunnel, side view

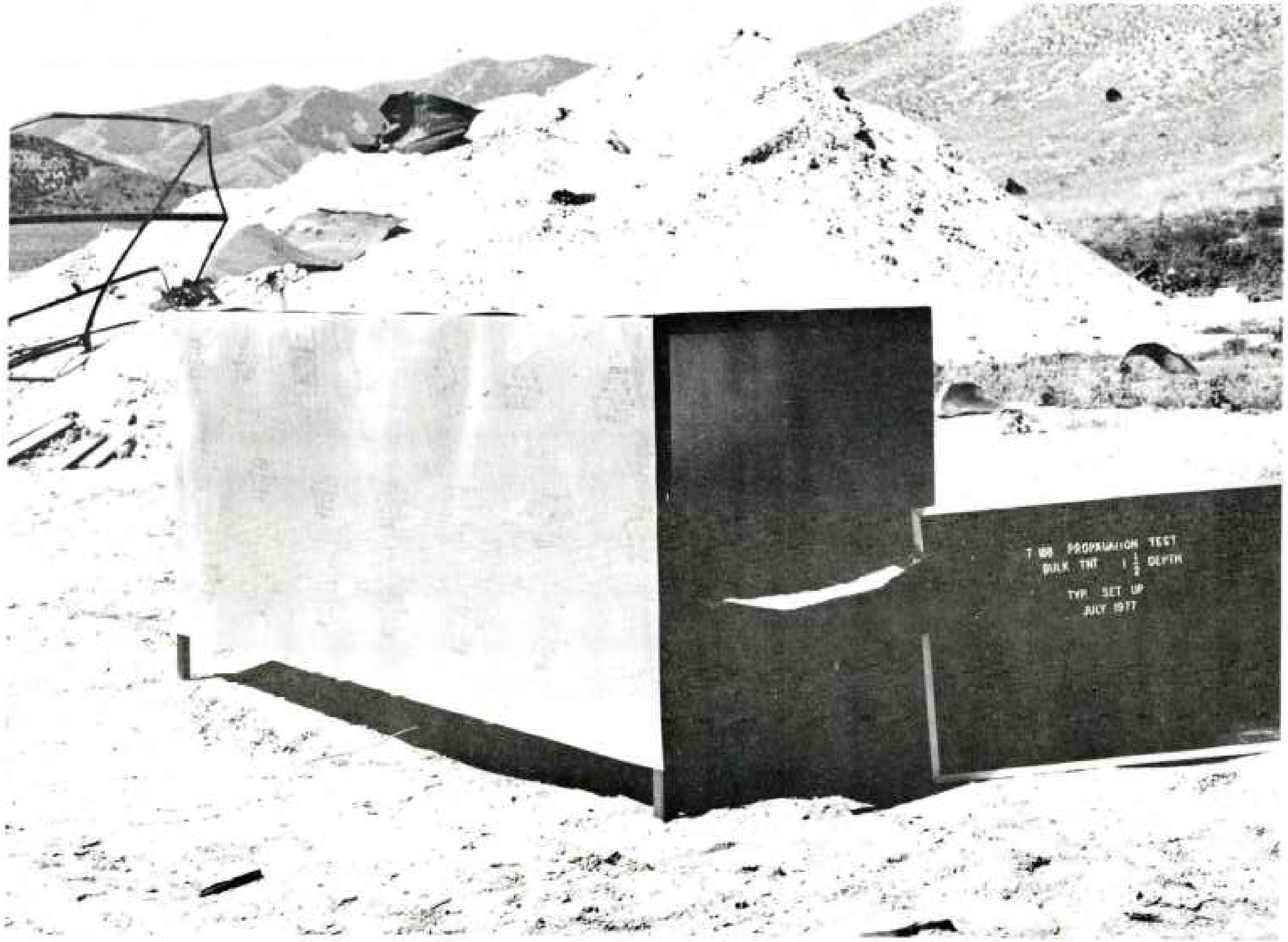

Fig 5 - Simulated tunnel, end view

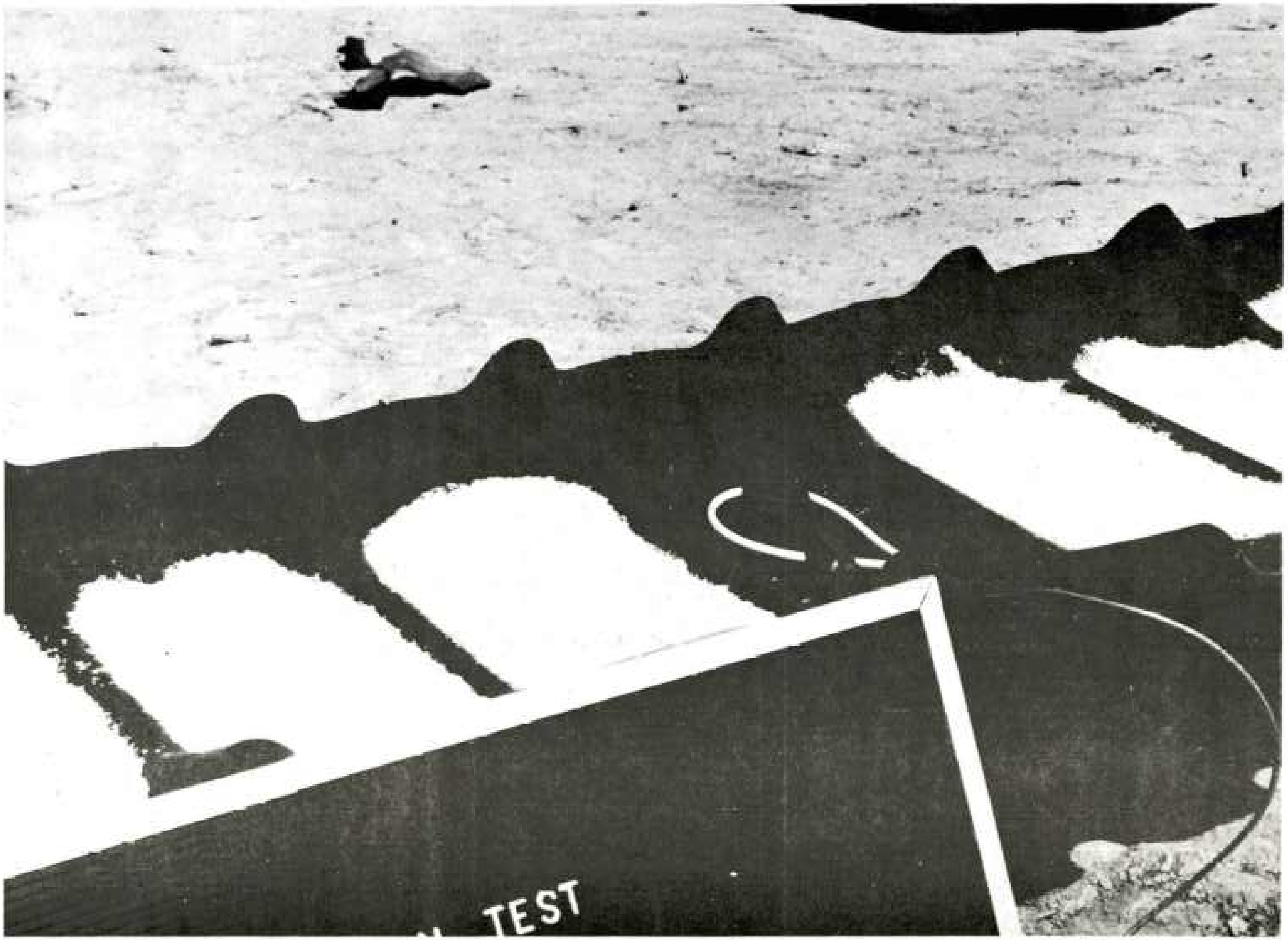

Fig 6 - Ignition setup

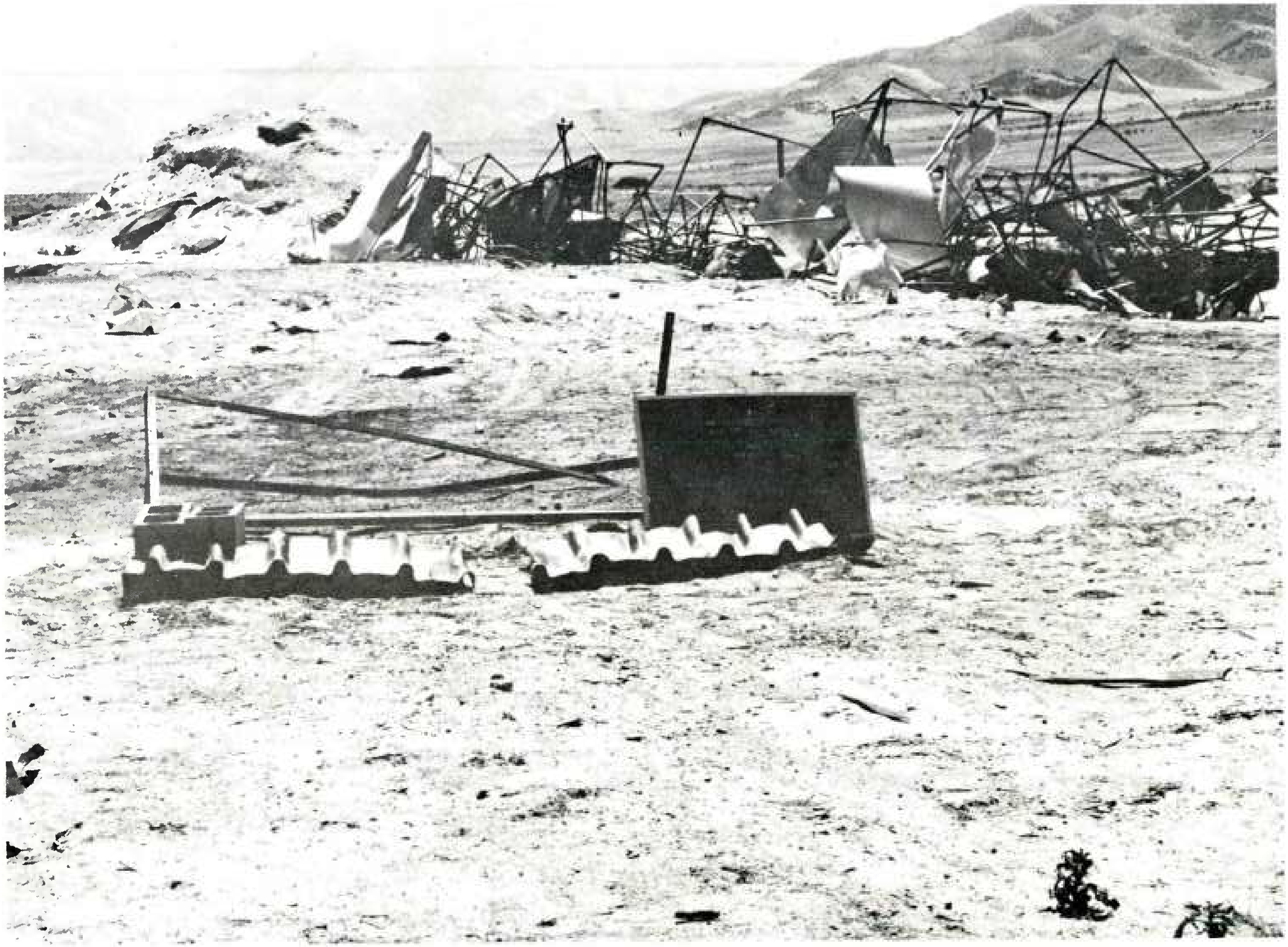

Fig 7 - Post-test results

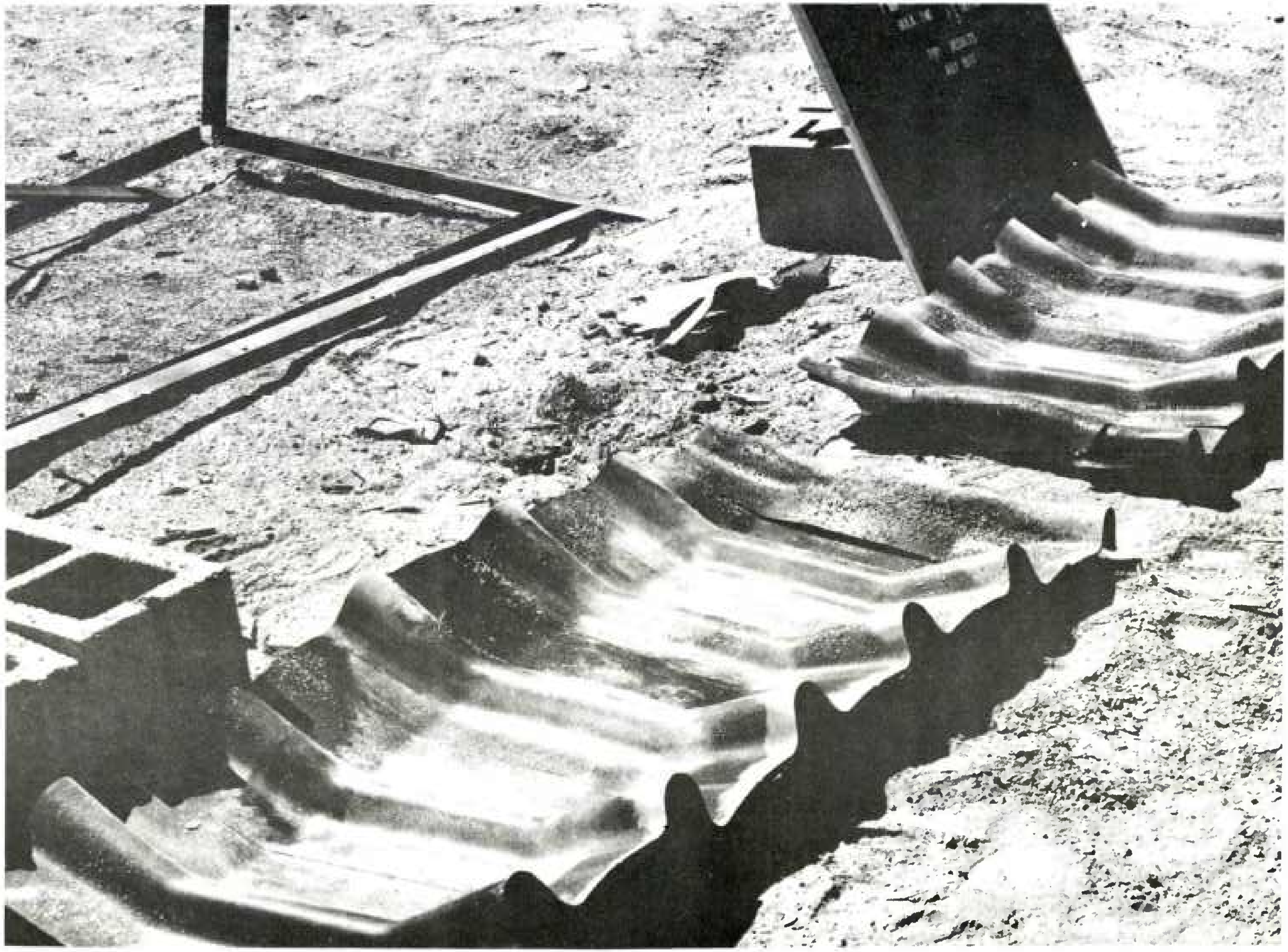

Fig 8 - Test results, closeup

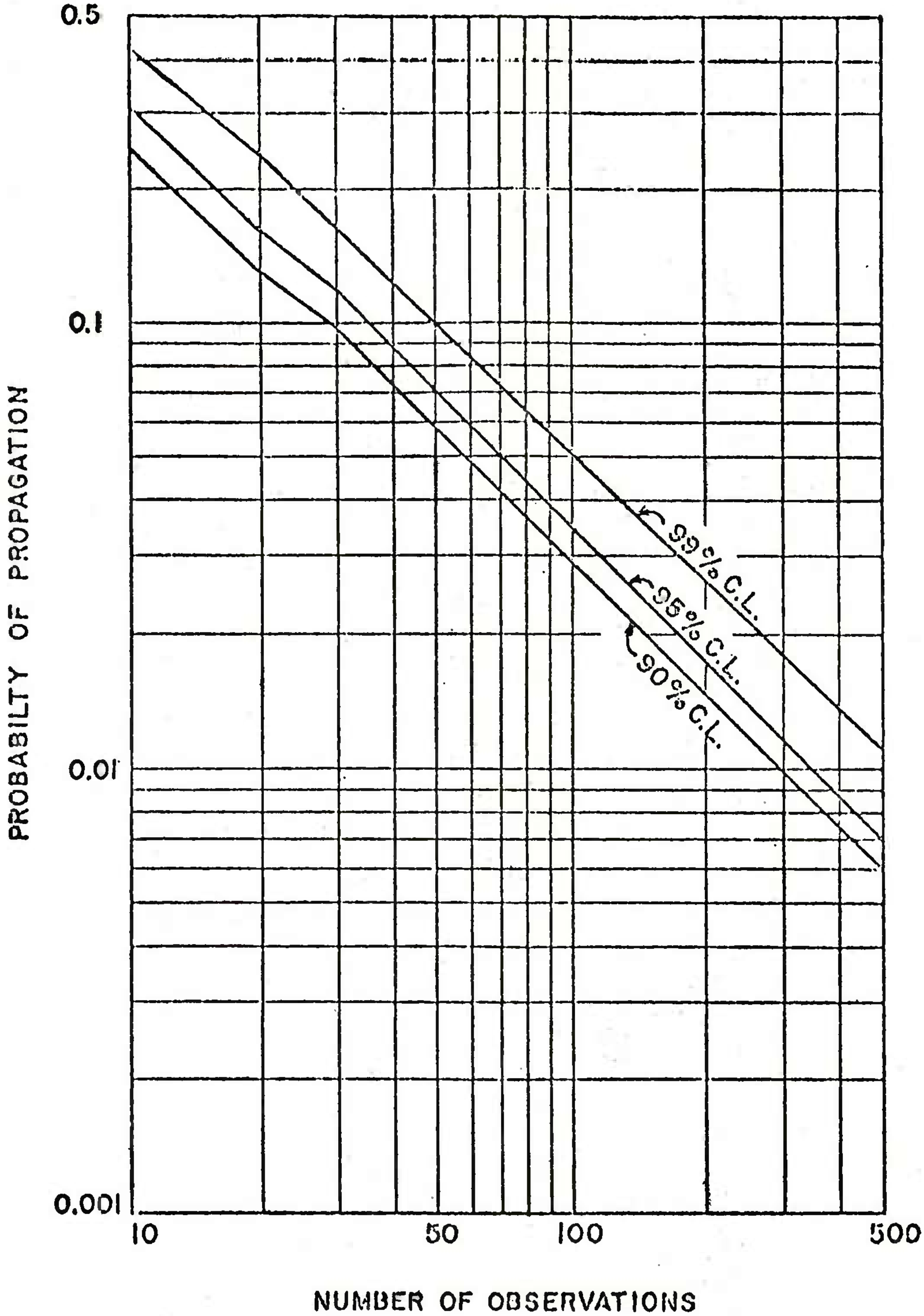

Fig 9 - Variation of propagation probability versus number of observations as a function of confidence level

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

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STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

Statistical Theory

Attempt has been made in the main body of this report to evaluate the possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results. This section of the report is devoted to mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by:

$$p = x/n \qquad \text{Eq. 1}$$

and, therefore, the expected value of (x) is given by:

$$E(x) = np \qquad \text{Eq. 2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as:

$$(1 - p_2)^n = \varepsilon \qquad \text{Eq. 3}$$

where $\varepsilon = (1 - \alpha)/2$ and $\alpha < 1.0$ Eq. 4

Use of Equation 3 is illustrated in the following example:

Example

Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95 percent based upon 30 observations without a reaction occurrence.

Given

Number of Observations (n) = 30
Confidence level (α) = 95 percent

Solution

1. Substitute the given value of (α) into Equation 4 and solve for ε:

   $\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$

2. Substitute the given value of (n) and value of (ε) into Equation 3 and solve for p_2:

   $\varepsilon = 0.025 = (1 - p_2)^{30}$

   or

   $p_2 = 0.116$ (11.6 percent)

Conclusions

For a 95 percent confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116; or statistically, it can be interpreted that in 30 observations, a maximum of 3.48 (0.116 x 30) observations could result in a reaction for a 95 percent confidence level.

Probability Table

Table A-1 shows the probability limits and the range of the expected value E(x) for different numbers of observations. Three confidence limits, 90, 95 and 99 percent, are used to derive the probabilities.

TABLE A-1

Probabilities of Propagation for Various Confidence Limits

Number of Observations	90 percent	C.L.	95 percent	C.L.	99 percent	C.L.
n	p_2	E(x)	p_2	E(x)	p_2	E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

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